EVALUATION AND MEASUREMENT OF HAND-TRANSMITTED VIBRATIONS

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Review article

Abstract: The goal of this work is the effect of vibrations on selected professionals through questionnaire survey and implementation of experimental vibration measurements on a hand of employee. The observation of vibration effects was chosen in a company, where products are being shaped with pneumatic instruments and there is a risk of an exposure of vibrations on the employees. In experimental part are described and evaluated questionnaire surveys conducted on selected risk factors. The reason is the realization of work with vibrating tools for a longer time, where some parts do wear-out and therefore there is a higher exposure to oscillation.

Keywords: Negative effects of vibrations, survey, experimental measurements of vibrations on hand.

Introduction

Vibration, the mechanical vibration, is a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed (as when a stretched cord produces musical tones or molecules in the air transmit sounds to the ear). (Lumnitzer et al., 2007; Očkajová et al., 2013).

The oscillation is the constantly recurring movement of the mass point. Vibrations are classified as physical factors. The vibration´s frequency [Hz] indicates the number of oscillations (deviations) from the original state per time unit ($1\ Hz = 1\ s^{-1}$). Vibrations are mechanical oscillations with frequencies greater than 25 Hz ($f > 25$ Hz). (Očkajová et al., 2013)

The most frequent sources of vibration and shake are heavy mechanisms, various mobile conveyors, electric motors, water, hydraulic, air pumps, and, last but not least, small vibrating tools in the working environment.

Vibration´s exposure is divided on the occupational hand transmitted vibration on the occupational hand transmitted vibration, on the occupational body-to-body transmitted vibrations, local vibrations, and overall vibration. (Suchomel et al., 2007)

Hand-transmitted vibrations are vibrations that come from handle hand tools or entire devices (eg polisher, pneumatic hammer, car steering wheel). (EPA, 2006)

Whole-body vibrations act on a stand, sitting or lying person as a whole across the support point. Local vibrations are transmitted to a certain part of the human organism. Overall vibrations are intensely transmitted to the whole body of the person. (Zelený, 2010)

A one from various sources of vibrations is a rotating machine. A rotating machine has one or more machine elements that turn with a shaft, such as rolling-element bearings, impellers, and other rotors. In a perfectly balanced machine, all rotors turn true on their centerline and all forces are equal. However Mobley (1999) says, in industrial machinery, it is common for an imbalance of these forces to occur. Vibration may be caused by instability in the media flowing through the rotating machine in addition to imbalance generated by a rotating element. Like rotating machinery, the vibration profile generated by reciprocating or linear- motion machines is the result of mechanical movement and forces generated by the components that are parts of the machine. Vibration profiles generated by most reciprocating and/or linear-motion machines reflect a combination of rotating and/or linear-motion forces. (Mobley, 1999)

Vibration in working environment

Working environment is an important living space where one is doing work. Employees remain at one workstation, leading to a higher probability of occurrence of accompanying health phenomena that

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are directly related to vibrations and noise. (Legáth, 2013)

Noise and vibration are among the strongest negative factors affecting the overall climate, well-being and workload of employees in the work environment statistical data in the SR (Fig. 1) issued by the National Centre for Health Information). The average occupational illness rate due to vibrations represents 18 % of the total number of illnesses in the last year and has a decreasing tendency (Fig. 1).

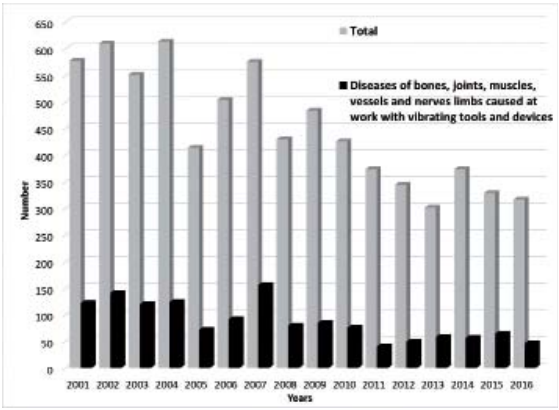

Fig. 1 Trends in number of diseases of bones, joints, muscles, vessels and nerves of limbs caused at work with vibrating tools and devices in the Slovakia in interval 2001-2016 (NCZI, 2017)

The theory, measurement, and effects of vibrations are more complicated than noise. The place of acoustic pressure is characterized by acceleration of vibrations. Vibration´s acceleration expresses the acceleration of the mass points in the transition to the marginal positions. (Suchomel et al., 2007)

Resources of vibration

In a damped system, some energy is dissipated at each cycle of vibration and must be replaced from an external source (Blake, 2010) The causes of vibration disease are mainly the use of manual instruments with high emission values of vibrations, vibrations (motor saws, pneumatic tools and special forestry machines). The most common cause of the disease is to exceed the permissible working time with these risk instruments and mechanisms. (Vance et al., 2010, Kijewski et al., 2001). Summary of some tool as resources of vibration (Tab. 1) was prepared by Griffin (1997).

Tab. 1 Some tools and processes potentially associated with vibration according to Griffin (1997)

Type of tool	Examples of tool types
Percussive metal-working tools	Reviting tools Caulking tools Chipping hammers Clinching and flanging tools Impact wrenches Impact screw drivers Nut runners Scaling hammers Needle guns Nibbiling machines and shears Swaging
Grinder and other rotary tools	Pedestal grinders Hand-held grinders Hand-held sanders Hand-held polishers Flex driven grinders or polisher Rotary burring tools Files
Percussive hammers and drills used in mining, demolition, road construction, stone working	Hammer drills Rock drills Tampers and rammers Road breakers Stone working tools
Forest and garden machinery	Chain saws Antivibration chains saws Brush saws Mowers Hedge cutters and trimmers Barking machines Strump grinders
Other processes and tools	Nailing gun Stapling gun Pad saws Circular saws Scabblers Engraving pens Shoe pounding up machines Vibratory rollers Concrete vibrothickeners Concrete levelling vibrotables Motorcycle handlebars Pedestrian controlled machines

The impact of vibrations on the human organism

Vibration poses a potential risk to workers as it may give rise to musculoskeletal, neurological and vascular disorders. (Griffin, 2008)

The influence of vibrations on the human organism arises from the resonance of the human organism (tab. 2). The negative impact of vibrations arises in two ways (Čerkala and Lalík, 2012):

1. Damage to certain parts of the body and organs due to shocks, strokes or kiks. These are vibrations with low frequency (lower vibrations per second) but with high amplitude (large deviation from the original equilibrium position).
2. Damage to health of body with long-lasting vibrations with low amplitude and higher frequency (high frequency vibration). These are vibrations with a high number of oscillations per second and a minimum deviation from the equilibrium position.

Recognition of occupational disease due to vibrations has been confirmed since 1998 in the working environment. Approximately 2 to 3 % of employees suffer from exposure in Europe and the US. (Suchoň and Zelený, 2017)

Tab. 2 Frequency of selected vibrating instruments according to Lumnitzer et al (2007) and examples of frequency bands in which the human body or its parts resonate according to Čerkala and Lalik (2012)

Tools	Frequency of vibration [Hz]	Body´s parts resonating
Electric scissors	2-6 12-15 20-30	Session person Standing person The soft parts of the body
Hand electric drill	30-40	Hands and shoulders
Pneumatic tools	30-60 60-90	Hands and shoulders Eyes

Diseases of bones, joints, muscles, vessels and nerves limbs caused at work with vibrating tools and devices by Slovak List occupational diseases are (NCZI, 2017):

- Injuries from vibrations mostly of vessels and nerves.
- Injuries from vibrations mostly of bends, of bones, of tendons and muscles.
- Other injuries from vibrations and combined injuries from vibrations.

The medical aspect of the evaluation of the diseases of workers exposed to vibrations can be divided into three basic groups (Kukučková et al., 2011):

1. Harmful syndrome peripheral vessels of the upper limbs (so-called Raynaud's phenomenon). Syndrome manifests itself as a distinct subjective sensitivity to cold, a feeling of rash, stiffness of the hands, and a change in the colour of the fingers to white (a consequence of the narrowing of the vessels in the limbs, especially the ends of the fingers). The health condition improves in a warm environment.
2. Disease of the vascular system, vasonucleosis. It is a disturbance of the vasculature of the limbs, specifically the fingers. The manifestations of the disease are muscle pain, reduced grip, and reduced sensitivity to touch.
3. Syndrome of bone, joint, tendon and muscle damage. His speech is pain in the wrist, shoulder and elbow joints, probable swelling of the forearm.

This paper presents preferred and maximum vibration values for use in assessing human responses to vibration and provides recommendations for measurement and evaluation techniques. In survey of employees opinion are working with pneumatic and electric tools to impact vibration. Experimental results determinate offers the levels of vibration acceleration on the selection of the power tool.

Regular and prolonged use of powered hand tools, or hand contact with vibrating surfaces during a daily work routine can cause an individual to develop hand-arm vibration syndrome (HAVS). (Hewitt et al. 2014)

HAVS is term from UK Reporting of Injuries, Diseases and Dangerous Occurrences Regulations and describes a collective term for the effect that vibration can have on the blood vessels, nerves, muscles, bones and joints of the hand and arm and is a reportable condition under the (Health and Safety Executive, 2013).

Griffin (1998) classifies types of disorders associated with hand-transmitted vibration exposure (Table 3). Some combinations of these disorders are sometimes referred to as hand-arm vibration syndrome (HAVS). (Griffin, 1998)

Tab. 3 Five types of disorders associated with hand-transmitted vibration exposure (Griffin, 1998)

Type	Disorder
A	Circulatory
B	Bone and joint
C	Neurological
D	Muscle
E	Other general (for example central nervous system)

Complex looking on vibration is offered by Kijewski et al. (2001). Their encyclopedia includes essential facts, background information, and techniques for modeling, analysis, design, testing, and control of vibration.

Legislative rules

Human health is result the interaction of impact environmental factors, working environment, genetics and lifestyle. The significance of harmful factors in the working environment is related to the amount with exposure on the human and the resulting health risks. (Zelený 2010; Zelený and Marková, 2015)

The introduction of measures to encourage improvements in the safety and health of workers at work, it was considered necessary to legislate on the specific problem of exposure to mechanical vibration. The Directive specifies two different types of vibration: vibration which, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders; and vibration which, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.

Slovak application of Directives about Occupational Safety and Health is Act 124/2006 Coll. Law of Occupational Safety and Health (OSH) sets out general principles of prevention and basic conditions for safety and health at work. The object of the Act 124/2006 Coll. is the exclusion of risks and factors underlying the emergence of occupational accidents and various illnesses or other damage to the health of employees.

The definition of exposure limit and action values for vibration exposure is given in STN EN ISO 5349-1: 2001 and STN ISO 26311-1: 1999.

STN EN ISO 5349-1: 2001. The standard describes the general and practical part of hand vibration measurement (Part 1 and Part 2).

STN ISO 26311-1: 1999 describes vibrations transmitted to the whole body of a person. Details of the practical instructions for vibration measurement at the workplace are given in EN ISO 5349-2: 2001. The above mentioned facts are also given in Annex no. 2 of the Government Regulation 416/2005 Coll.

Material and methods

Methods and possibilities of vibration measurement in working environment

The factors that monitor daily exposure to vibration are the frequency-weighted vibration force (level) and the time of exposure of the person to this vibrational effort. The greater the force or the longer the exposure lasts, the greater the exposure of the person to the vibrations. (EC, 2007)

Vibrations or mechanical vibrations are characterized by amplitude [m] (maximum equilibrium deflection) and velocity in [$m.s^{-1}$], acceleration and [$m.s^{-2}$]. The parameter measured in the vibration impact assessment is the vibration acceleration level (effective vibration acceleration value) L (a).

Measurement procedure according to STN EN ISO 5349-2: 2001

The full vibration image must be measured in three axes (Fig. 2). Measured vibration exposure values are:

- a_{hwi}: - the resulting oscillation value [$m.s^{-2}$]. The value is calculated from three values of the frequency-weighted vibration acceleration transmitted to the hand in the direction of the three axes a_{hwix}, a_{hwiy}, a_{hwiz},
- During of Ti (in 1 day) is the time of vibration for the selected operation.

The basic experimental parameter is the daily exposure of vibration A (8).

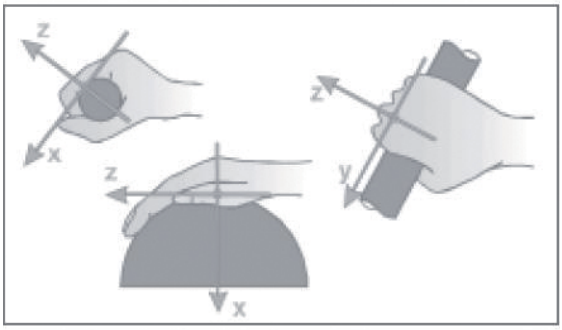

Fig. 2 Axes of vibration measurement of hand and shoulder vibrations (EC, 2007)

The objective evaluation of the daily oscillation exposure is based on a detailed survey of the operation being performed. The measurement method was chosen based on the nature of the work environment, type of work, product and vibration source. The operation on hand pneumatic tools has been selected for experiment.

The measurement option was selected as a "short-time measurement of intermittent tool operation". The reason for selection was the movement of the worker in the area. The worker often leaves manual pneumatic tools and turns the workpiece and vice versa.

Short-term measurements cannot be performed reliably during the work process under certain conditions. The "daily vibration exposure" measurement is performed with a very short vibration exposure time. Measurement is done by simulation.

The operation is adjusted to an uninterrupted and longer time, but with the aim of getting closer to real conditions. The measurements were made in three replicates for a total length of at least 1 minute. (STN EN ISO 5349, Part 2)

Fig. 3 a) Grip of the crane driver by right hand and b) measurement equipment of the Human Vibration Analyzer type 4447 (Suchoň, 2016)

Affected operations were measured continuously for 30 minutes. The employee works with a pneumatic tool for at least 10 minutes over a 30-minute interval. Part of the measurement measured the times as long as the operator is exposed to vibration exposure during daily work change. The uncertainty of daily exposure assessment has not been applied. (Markova et al. 2017)

The 3-axis piezo-crystalline sensors are usually used for detecting the movement of the oscillating surface (hand). The piezo-crystalline sensor was placed on the surface of the hand in the middle of the palm, where the vibration enters to the body. Measurement was performed with a 4447 Human Vibration Analyzer (Fig. 3).

Measurement performance is significantly influenced by physical factors. (Xi et al., 2014, Griffin, 1997) Physical variables relevant to the effects of hand-transmitted vibration are magnitude of vibration, frequency of vibration, direction of vibration, duration of vibration, area of contact with vibration, contact force (grip force and push force), finger, hand, and arm posture and environment (for example temperature). (Griffin, 1997)

Calibration of the measuring instrument was by the so-called vibration exciter. Calibration was done for all three axes. (Suchoň and Zelený, 2017) More information about systems of calibration is described by Brandt (2016).

The vibration source is a pneumatic sander type: GDS 050 250 BXI (declared acceleration reported by the manufacturer: 2.5m.s^{-2}, weight: 0.9 kg, noise: 81.7 dB, maximum allowed working time for 1 change: unlimited).

Results and discussion

A worker who handles the workpiece by means of a pneumatic sander is exposed to vibration. Total measurement time 28 min (Tab. 4). The hand grip strength force for workers has been classified

Tab. 4 Results of hand exposure vibration measurement. Table of measured values of right-handed worker

Experimental values		**Normalized values according to Slovak Stadard No. 416/2005 Law**		
a_{wegT} [m.s^{-2}]		**Maximum vibration acceleration value**		**Declared acceleration reported by the manufacturer**
		Action value	**Limit value**	
Course 1 (x)	2,8±0,10	2,5	5	2,5
Course 2 (y)	2,9±0,08			
Course 3 (z)	2,78±0,13			
Total exposure time Tc [s]	198±1,65			
The resulting acceleration from the measured values as an average value	2,76			
Normalizing acceleration of vibrations a_{weg8h} [m.s^{-2}]	2,74±1,13			
The resulting acceleration [m.s^{-2}]	2,44±1,42			

through worker's age and their technological work. (Azmira et al., 2015) Fundamentals of limits and methods of measurement of exposure to vibration on hand and body were given by Rasmussen (1983), Griffin (1990) and Gordon (1991).

The assessment of the employee's opinion on the impact of vibrations in the performance of their activities was carried out by the employees from production plants using pneumatic tools were asked to answer the questions. Number of respondents 20 (11 founders) with a return of is 65 %. The survey was conducted in December 2015 and January 2016, November and December 2016. The survey was conducted by male employees aged 30-59 years. All respondents had completed secondary education.

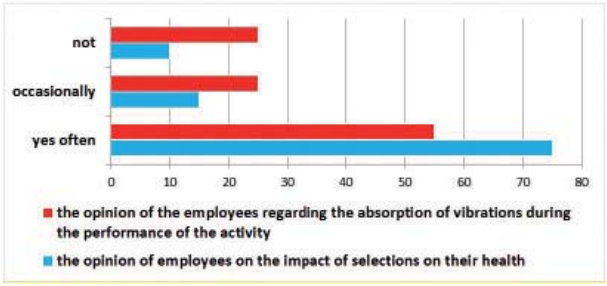

Fig. 4 The opinion of the employees regarding the absorption of vibrations during the performance of the activity (circle in) and the opinion of employees on the impact of selections on their health (circle out)

The questionnaire survey in selected professions clearly demonstrates the opinion of the respondents about the existing impact and the risk of exposure to vibrations (Fig. 4).

Everyone had positively answer on the question Do you know of the impact and consequences of vibrations on human health? The results of the questionnaire survey showed little employee´s interest in further training to increase the level of occupational health and safety.

Conclusion

The observation of vibration effects was chosen in a company, where products are being shaped with pneumatic instruments and there is a risk of an exposure of vibrations on the employees. Implementation of the experiment - the measurement of vibrations acting on the hand when working with the pneumatic sander (type: GDS 050 250 BXI), showed an exceedance of the valid values.

The results of vibration measurements in the profession of right-handed worker exceeded the values declared by the manufacturer. The resulting acceleration from the measured values as the mean value of the a hwi was 2.76 $m.s^{-2}$, with the manufacturer declaring 2.5 $m.s^{-2}$.

Acknowledgments

The scientific work was created using the instrumentation obtained under the project OP Research and Development - ITMS 26210120024 "Recovery and Building of Infrastructure for Ecological and Environmental Research at the UMB".

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